Recent Research on Antennas for Wireless in Australia

Presenter: Trevor S. Bird
Principal, Antengenuity and CSIRO Fellow

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CSIRO

Overview

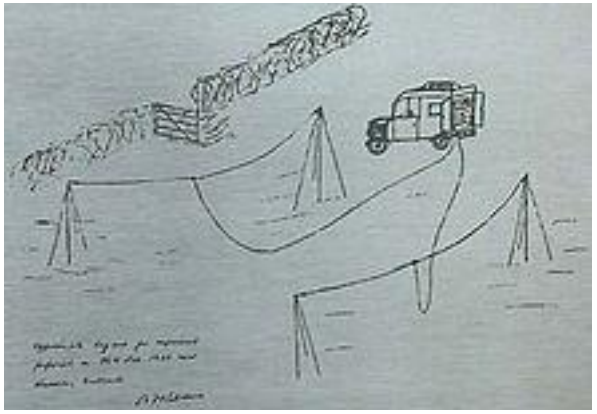
- The Wireless revolution
- History of Australian Wireless
  - Milestones
  - CSIR
  - Importance of Radio Research Board
- Current Antenna Research in Australia
  - Snapshot of projects from 7 universities, DSTO & CSIRO
- Concluding Remarks
- Acknowledgement

The Wireless Revolution

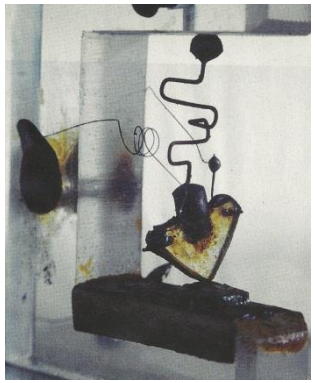
- What is it?
- History
  - Prior to 1960s
  - IEEE standards
  - Mobile
  - Wi-Fi
- Antennas and propagation are significant!

Wireless History in Pictures

1922 – first mobile phone

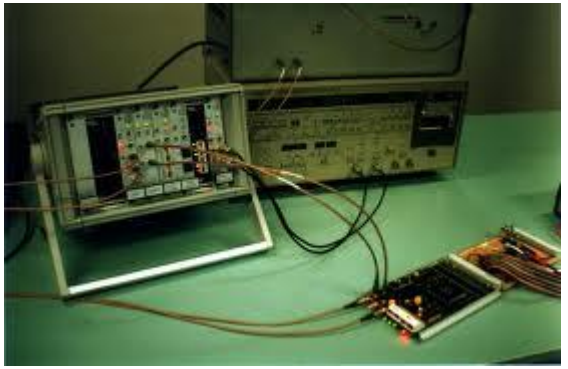


1935 – first aircraft radar detection



1947 – first transistor

1963 – first synch. satellite



1993 – first 802.11a modem (CSIRO)

Australia – "Tyranny of Distance"

- Overland Telegraph 1872
- "We have this day, within two years, completed a line of communications two thousand miles long through the very centre of Australia, until a few years ago a terra incognito believed to be a desert", first message Charles Todd (1872).

Route of Overland Telegraph

Telegraph Station Alice Springs, 1872

Milestones in Australian Wireless – I

- 1905: Marconi company builds first two-way wireless telegraphy station at Queenscliff, Victoria
- 1908: Experimenter Harry Sutton holds long distance record for radio transmission
- 1910: First portable radio built by Sutton
- 1910: Amalgamated Wireless Australia (AWA) is formed, merging the Australian interests of Marconi, Telefunken and local business
- 1919: Radio transmissions by Ernest Fisk
  - first direct wireless message from England to Australia is received at AWA's Wahroonga, Sydney, station
  - who broadcast the Australian national anthem from one building to another at the Royal Society of NSW
- 1923: PMG Research Labs established
- Commercial radio commences in the 1920s
  - first public broadcast in 1923
  - first radio station 2FC in Sydney
- 1927: Development of pedal wireless for the flying doctor by Alfred Traeger which could receive and transmit messages across a distance of 1,500 km

Milestones in Australian Wireless – II

- 1927: Establishment of Radio Research Board in 1920s
  - Investigated fading, atmospherics & other problems with broadcasting
  - Initial members Madsen (Syd. Uni), Rivett (CSIR) & Brown (PMG)
- 1934: Significant radio expertise in Australia. Eg. F. Langford-Smith's "Radio Designer's Handbook" continued in world wide publication until 1950s
- 1935: World's second coaxial submarine cable is installed between Victoria and Tasmania, via King Island
- 1939: Short-wave radio service Australia Calling (later renamed Radio Australia) begins broadcasts from Sydney
- 1939: Radar developed – based on knowledge gained by Martyn in Britain
- 1940: Piddington conducts radar moon bounce experiments
- 1945: PMG Research Laboratories commence conducting radio telephony investigations, extended to VHF and UHF
- 1948: Experimental FM broadcasts commence
- 1953: Television act passed
- 1956: First regular television broadcasts commence – Melbourne Olympics

Milestones in Australian Wireless – III

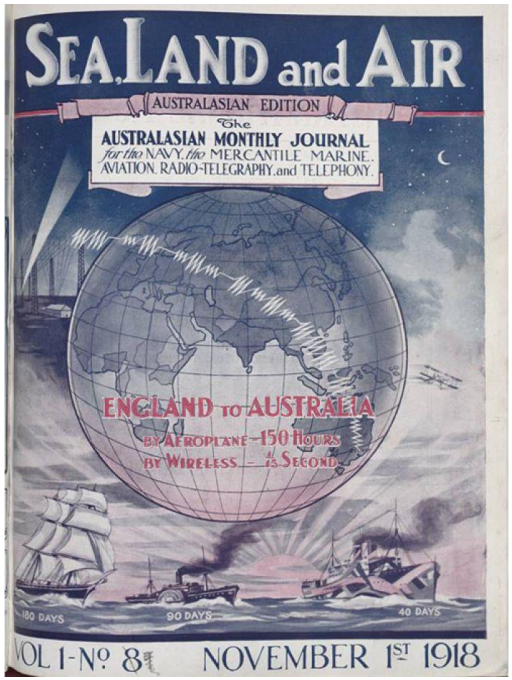
- 1959: First broadband telecommunications microwave link carries traffic between Melbourne & Bendigo
- 1960s: Installation of microwave trunk system around the country
- 1961: Parkes radiotelescope opened & first signals obtained
- 1963: Australia leader in Interim Communications Satellite Committee (ICSC), the initial policy decision making body of INTELSAT
- 1964: First satellite reception/transmission from WA
- 1964: Work commenced on corrugated feed horn for Parkes
- 1968: Tenders called for a standard A earth station at Moree
- 1969: Propagation experiments in preparation for domestic satellite system
- 1971: Development of Interscan microwave landing system commences
- 1974: Decision that FM should operate in Australia in the VHF band
- 1978: ICAO selects Interscan as international MLS standard
- 1981: Decision to create a domestic satellite system AUSSAT
- 1985: AUSSAT I the first geostationary satellite is operational
- 1989: Work commenced on 60GHz indoor wireless
- 1993: Provisional patent for OFDM-based signalling for wireless LAN
- 1997: CSIRO patent used in IEEE 802.11a standard

Milestones IV

First public radio broadcast 1923.

Ernest Fisk founder of AWA in 1911.

Pedal wireless1927.

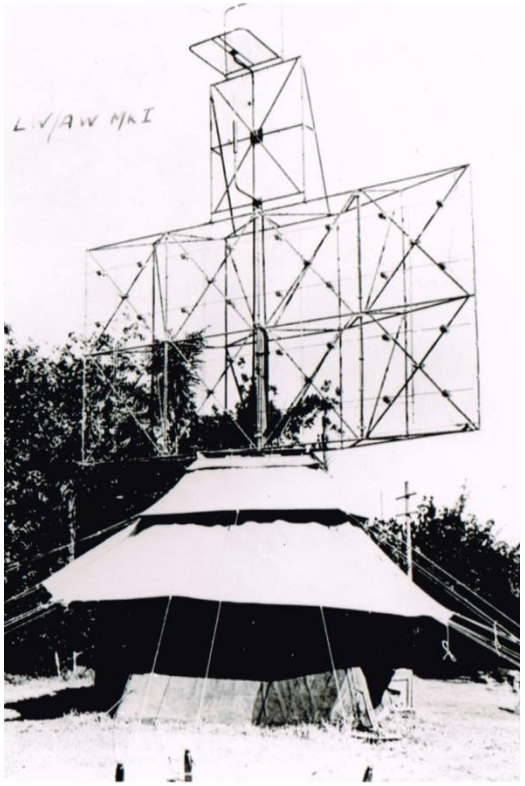


First wireless transmissions from Australia to England 1919.

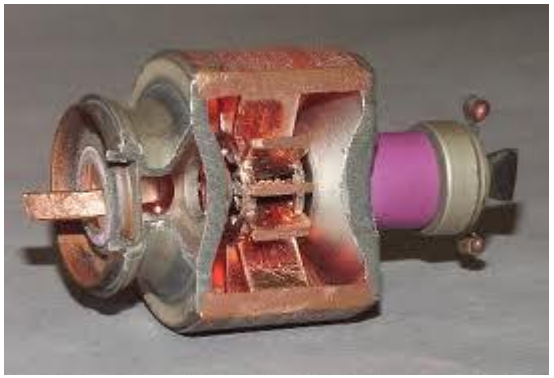
Milestones – CSIR in 1940s

- Creation of CSIR Radiophysics in 1939 for development of radar
- Strong radio frequency group led by former EMI engineer Joe Pawsey
- Development of portable radar sets, antennas, magnetrons (in Melb. under Leslie Martin)
- Several types of portable radar sets ultimately used by US and Australian forces in the Pacific
- During the early 1940s research led to scattering and reception of radar signals from the moon – Piddington
- Radio astronomy began at several sites after 1947

Milestones – CSIR Radar Days



Lightweight air warning radar Mk I. (1942)



Early magnetron

VT90 Micropup triode for 200MHz

Shore defence radar Dover Heights used for first solar observations, (1947)

Radio Astronomy in Australia

- Commenced after 1945. Led by Joe Pawsey
- Initially used array antennas developed for radar in interferometer arrangement
- Development of long linear arrays in the 1950s
- – Mills Cross (after Prof. Bernard Mills)
- – Chris-cross (after Prof. Chris Christianson)
- Dish antennas major advances
  - Parkes 210ft radio telescope opened in 1962
  - Australia Telescope compact array 1980s
  - L-band multibeam feed fitted to Parkes in 1995

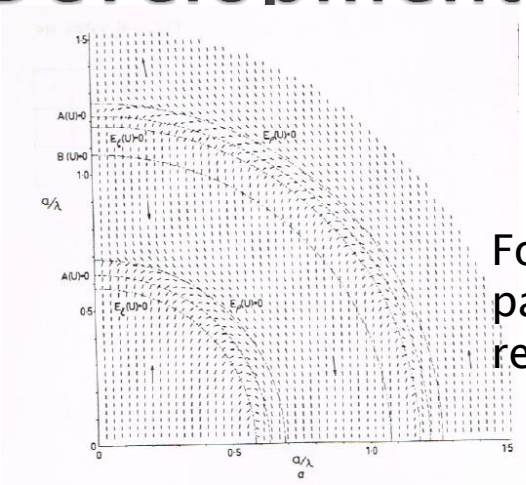
Early Radioastronomy

32x3m dish Chris-cross at Potts Hill reservoir, Sydney (1954)

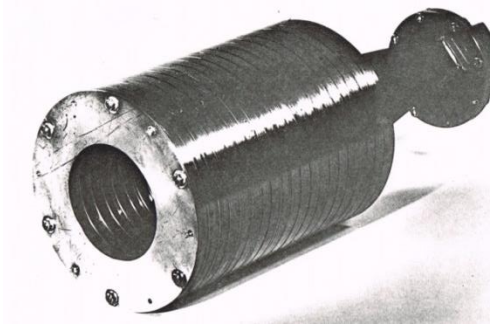
First focus cabin lifted into place at Parkes (1961)

Early Corrugated Horn Development

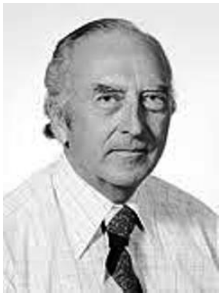
- Three groups in 1960s:
- Cutler (USA) Bell Labs – corrugated surfaces & early rectangular horn. This led to Kay's scalar feed
- Minnett & Thomas (Australia) – field matching in parabolic reflector required hybrid modes
- Clarricoats (UK) – extension of previous work on low-loss waveguides



Focal field parabolic reflector (1968)

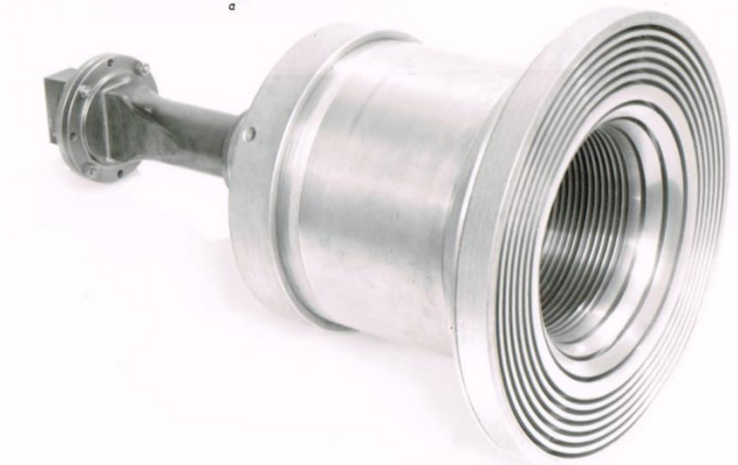


First prototype waveguide horn (1966)



H.C. Minnett

B.M. Thomas

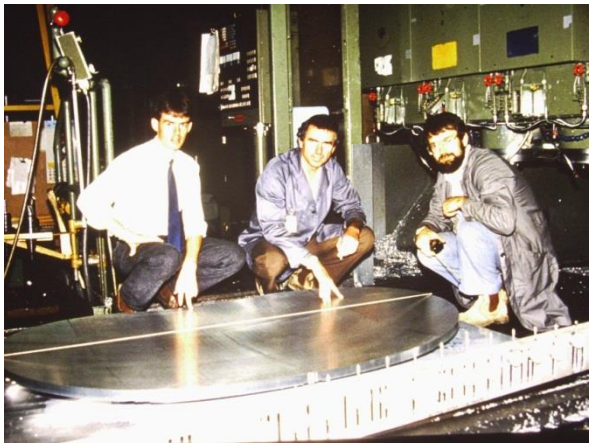


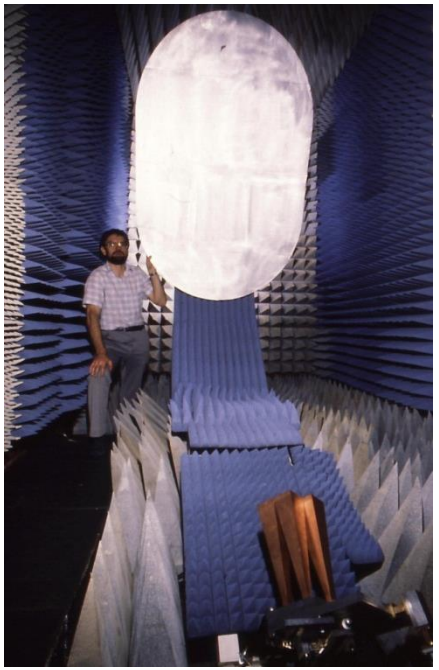
A two-mode-hybrid-mode corrugated horn first used at Parkes (1968). Used during Apollo 11 moon landing.

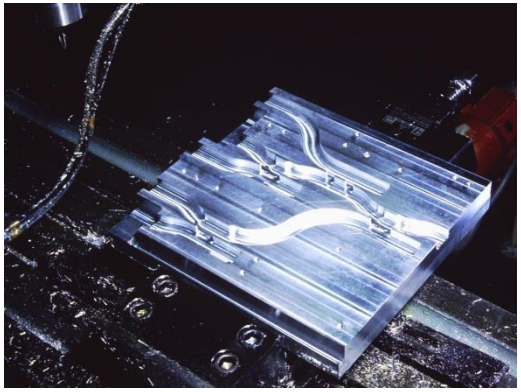
Australian Domestic Satellites

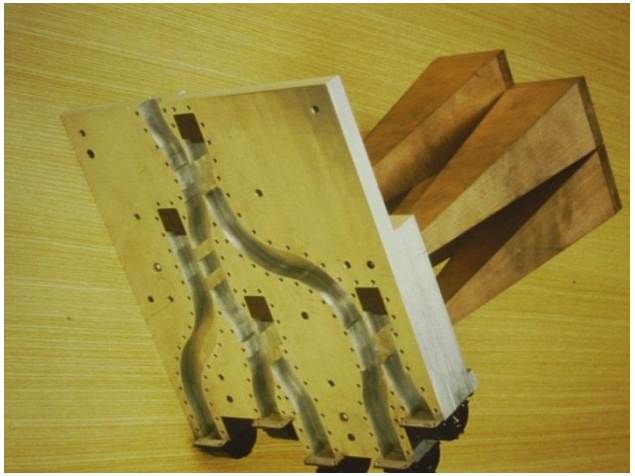
- Decision to have domestic system AUSSAT in 1981 at Ku-band – now Optus
- Need for portable ground terminals – led to research in CSIRO and universities
- 1989: On-board satellite antenna development by CSIRO for AUSSAT II
- 1987: Multibeam reflector antennas proposed as a way of accessing the three AUSSAT satellites located 4° apart.
  - This resulted in further developments & 5 antennas now operational in Europe.
- Australian orbit satellite FEDSAT built in the 1990s led to research & experiments in K-band antennas & earth stations

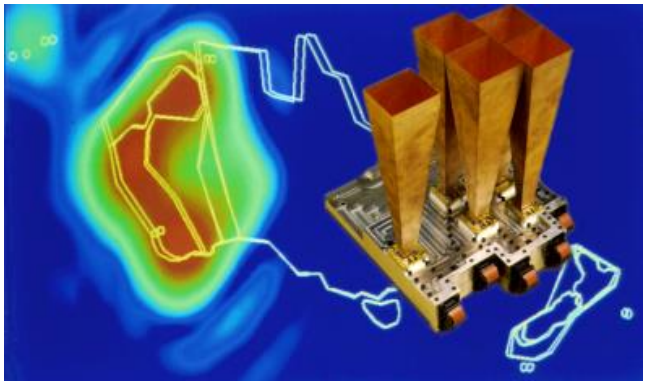
AUSSAT



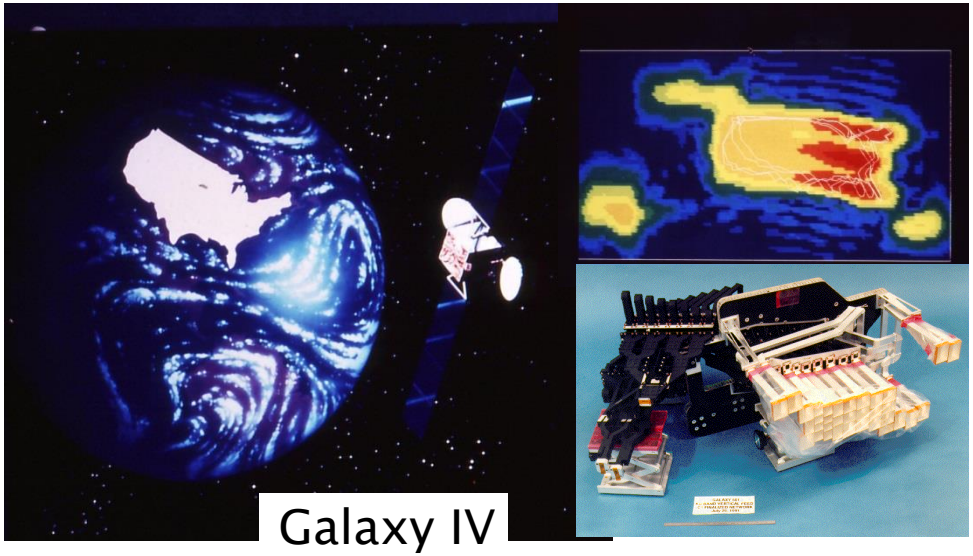








Follow-on Satellite R&D

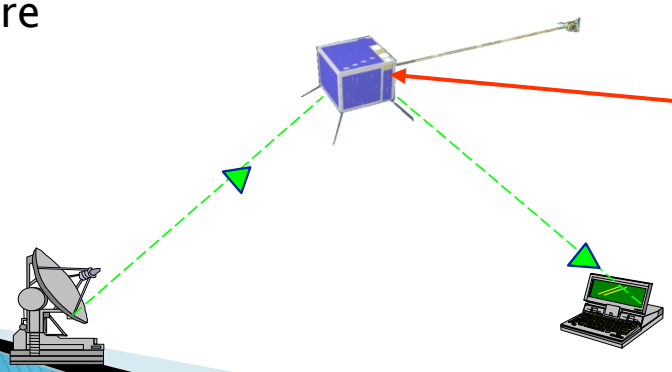


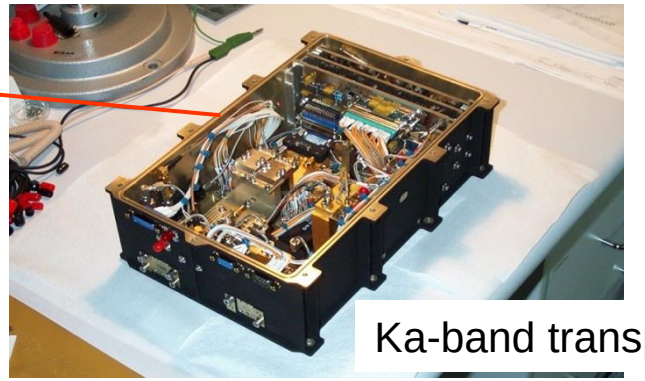
Galaxy IV

Lightweight components

FedSat Ka-band

- FedSat demonstrated a 30/20 GHz radio link for future Internet access
- CSIRO developed a Ka-band transponder with antennas, MMICs & space flight hardware





Ka-band transponder

WLAN

- Discussion of concepts began in 1989
- 60GHz selected to achieve 50Mbs internet
- Antennas & propagation work commenced in 1990
- Propagation measurements showed that walls, floors & ceilings created significant reflections
- These showed that 50Mbs could not be achieved with conventional modulation schemes
- Work by O'Sullivan, Daniels, Percival, Ostry & Dean resulted in the CSIRO WLAN patent

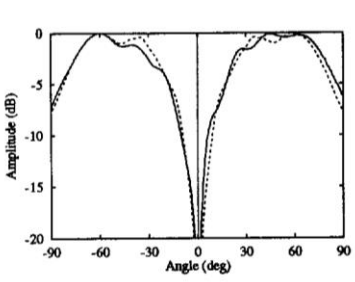


Fig. 3: Radiation pattern of ring-slot antenna excited in the second-mode. —— measured; – – – calculated

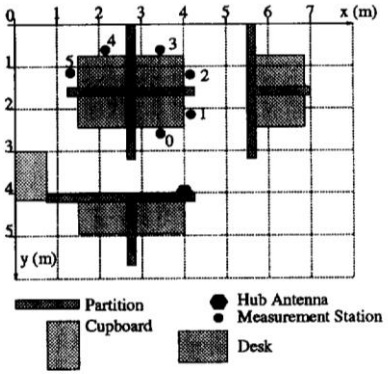


Fig. 6: Open plan office used in propagation measurements.

Ref. Bird et al., IEEE Antennas & Propagation Society Symposium, Seattle, USA, 19-24 June 1994, pp. 336-339

US WLAN Patent 5,487,069 – 1996

Inventors: O'Sullivan, Daniels, Percival, Ostry & Dean

US005487069A

United States Patent [19]
O'Sullivan et al.

[11] **Patent Number: 5,487,069**
[45] **Date of Patent: Jan. 23, 1996**

[54] **WIRELESS LAN**

[75] Inventors: **John D. O'Sullivan**, Ermington; **Graham R. Daniels**, Willoughby; **Terence M. P. Percival**, Lane Cove; **Diethelm I. Ostry**, Petersham; **John F. Deane**, Eastwood, all of Australia

[73] Assignee: **Commonwealth Scientific and Industrial Research Organisation**, Australia

[21] Appl. No.: **157,375**

[22] Filed: **Nov. 23, 1993**

[30] **Foreign Application Priority Data**

Nov. 27, 1992 [AU] Australia PL6069

[51] **Int. Cl.**[6] **H04B 7/01**

[52] **U.S. Cl.** **370/94.3**; 375/284; 375/348; 455/52.3; 455/65

[58] **Field of Search** 375/34, 39, 51, 375/57, 58, 99, 101, 254, 261, 279, 284, 285, 346, 348; 370/95.3; 455/56.1, 54.1, 63, 65, 52.3

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IEEE Transactions on Communications, vol. 39, No. 5, May 1991, New York US pp. 783-793 E. F. Casas et al. 'OFDM for Data Communication over Mobile Radio FM Channels—Part I: Analysis and Experimental Results' p. 784, left col., line 1—right col., line 2; FIG. 1 p. 790, right col., line 18-line 22.

42nd VTS Conference vol. 2, May 1992, Denver US pp. 819-822 T. Le-Ngoc 'A CSMA/CD Portable Data System Using Adaptive Reed-Solomon Coding' p. 820, left col., line 2-line 9.

IEEE Transactions on Communications, vol. 33, No. 7, Jul. 1985, New York US pp. 665-675 L. J. Cimini Jr. 'Analysis and Simulation of a Digital Mobile Channel Using Orthogonal Frequency Division Multiplexing' par. I-par. II. Par IV.

Primary Examiner—Benedict V. Safourek
Attorney, Agent, or Firm—William S. Frommer

[57] **ABSTRACT**

The present invention discloses a wireless LAN, a peer-to-peer wireless LAN, a wireless transceiver and a method of transmitting data, all of which are capable of operating at frequencies in excess of 10 GHz and in multipath transmission environments. This is achieved by a combination of techniques which enable adequate performance in the presence of multipath transmission paths where the reciprocal of the information bit rate of the transmission is short relative to the time delay differences between significant ones of the multipath transmission paths. In the LANs the mobile transceivers are each connected to, and powered by, a corresponding portable electronic device with computational ability.

72 Claims, 8 Drawing Sheets

The present invention discloses a wireless LAN, a peer-to-peer wireless LAN, a wireless transceiver and a method of transmitting data, all of which are capable of operating at frequencies in excess of 10 GHz and in multipath transmission environments. This is achieved by a combination of techniques which enable adequate performance in the presence of multipath transmission paths where the reciprocal of the information bit rate of the transmission is short relative

Importance of Radio Research Board

- In early days it recruited experienced personnel often ex-patriot Australians that led radio development for 20 years. Including G. Builder, A.L. Green, D.F. Martyn, G.H. Munro, J,J. Piddington & O.O. Pulley
- The RRB Chair Prof. Madsen was central to the formation of Radiophysics Lab that resulted in Australian radar and radioastronomy
- After 1950 it was funded by CSIRO, PMG (Telecom) and OTC to provide small research to researchers working on wireless projects
  - eg. grants from RRB for university work that led to CSIRO success in the AUSSAT II project
- The successor ATERB (Aust. Telecom & Electron. Research Board) provided postdoc Fellowships and was involved in sponsoring conferences.
- ATERB continued until 1995. There is currently no similar grants body in Australia providing support for wireless activities.

Current Antenna Research in Australia

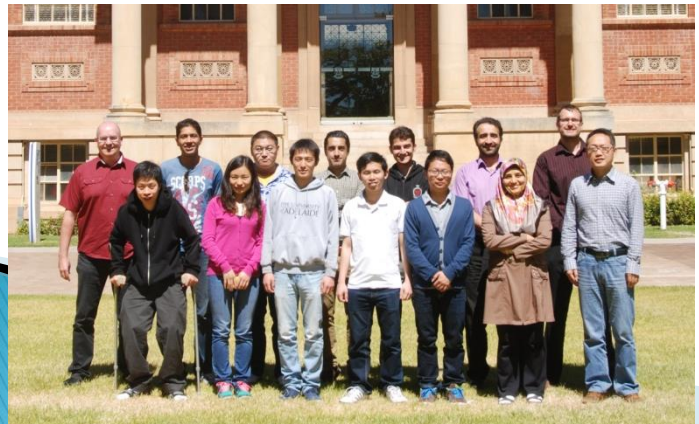
- Snapshot provided by samples of work from:
- Univ. of Adelaide (S. Aust.)
- DSTO (S. Aust)
- Griffith Uni. (Qld)
- La Trobe Univ. (Vic.)
- Macquarie Univ. (NSW)
- Univ. of NSW
- Univ. of Queensland
- RMIT Univ. (Vic.)
- CSIRO (NSW)

Applied Electromagnetics Group
University of Adelaide

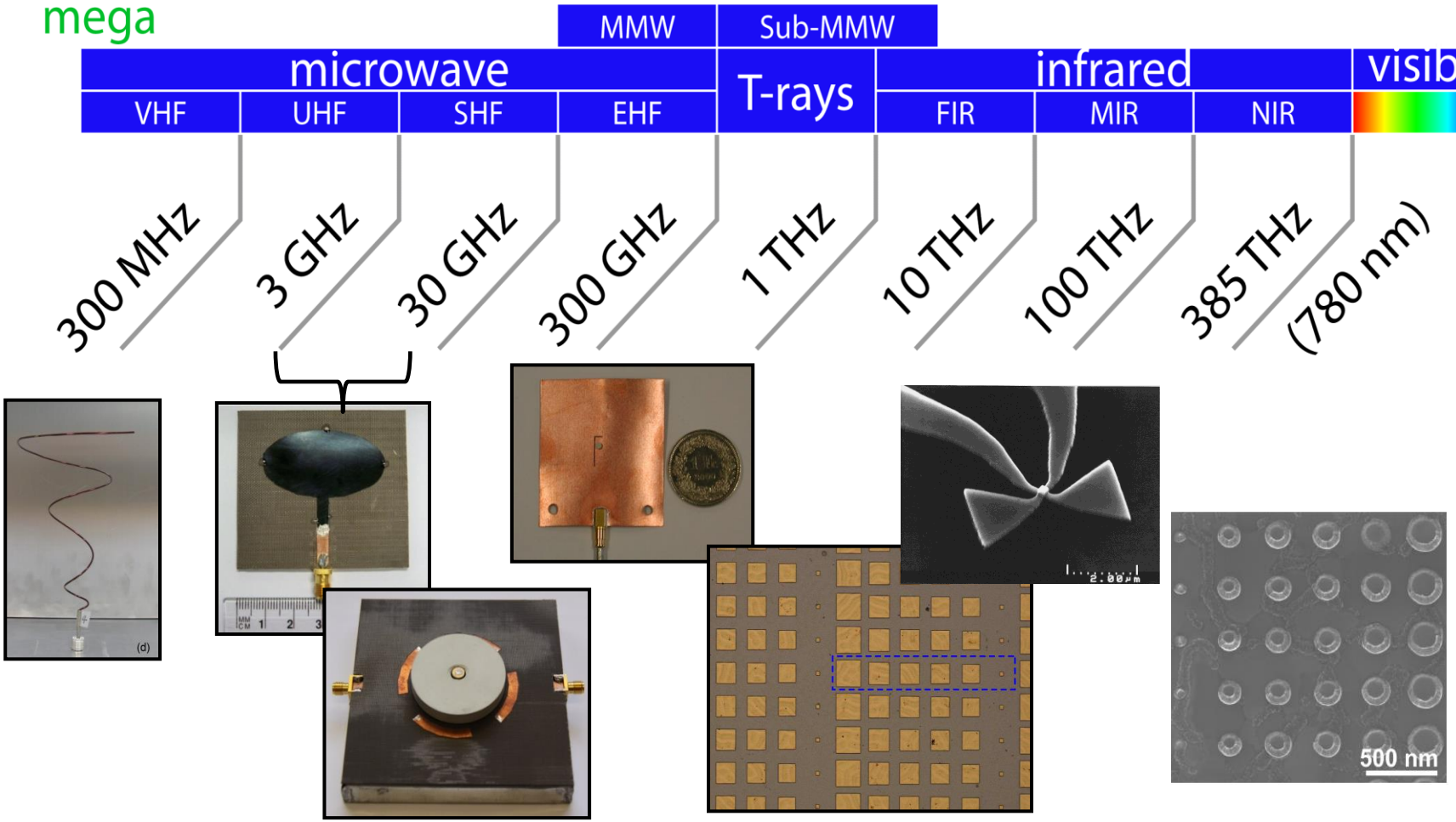
Electrical Engineering
University of Adelaide, Adelaide S. Aust.
Leader: A/Prof. Christophe Fumeaux

Topics at University of Adelaide

- Computational electromagnetics
  - conformal time-domain methods
- Dielectric resonator antennas
  - multi-function multi-port DRAs
- Antennas and associated structures using unconventional materials
  - conductive polymers
- Metamaterial-inspired structures for microwave and terahertz frequencies



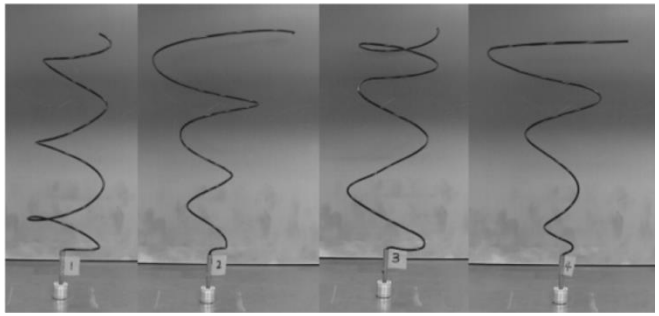
Adelaide Applied EM Group
Antennas across the spectrum

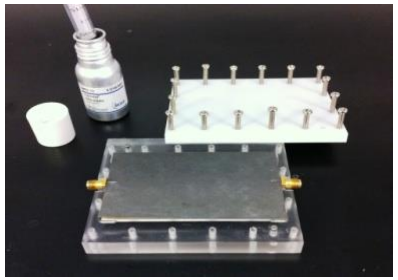


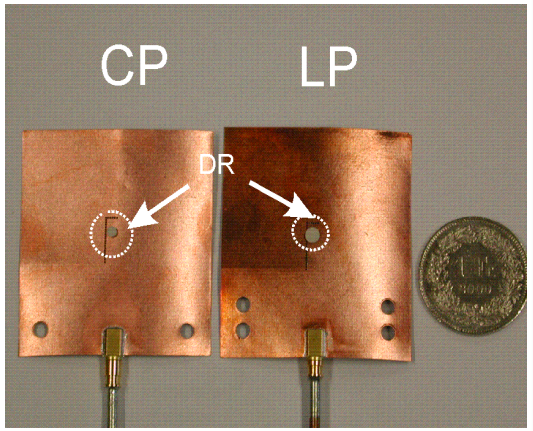
Microwave and mm-wave antennas

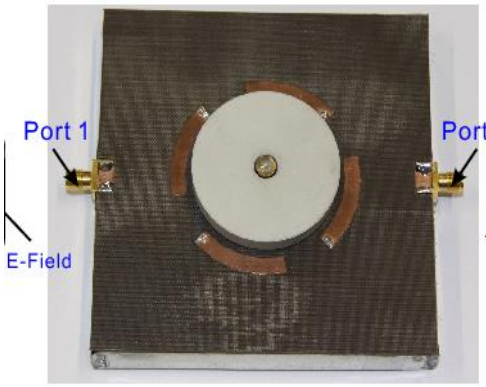
Microwave antennas & components:

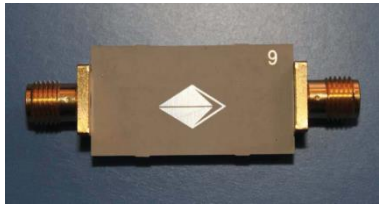
- Dielectric Resonator Antennas
- Conducting polymers
- Optimized antennas
- Reconfigurable antennas & FSS
- Substrate-Integrated Waveguides
- Metamaterial filters & sensors



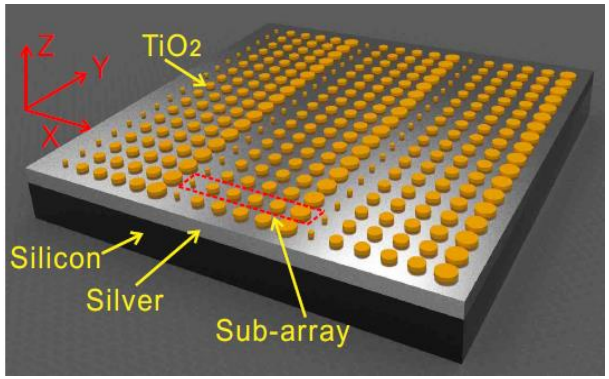


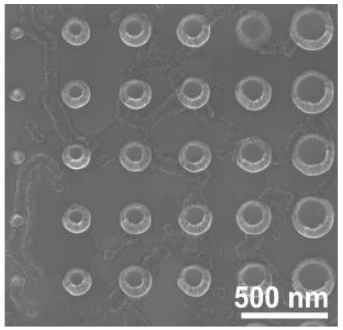




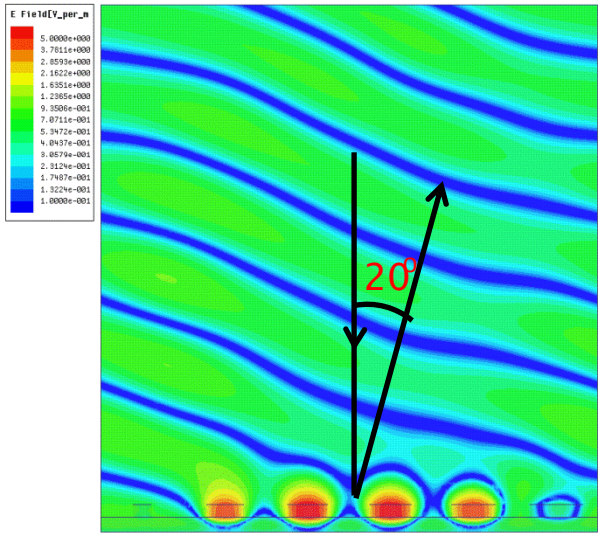


Dielectric Resonator Optical Antennas (633 nm)

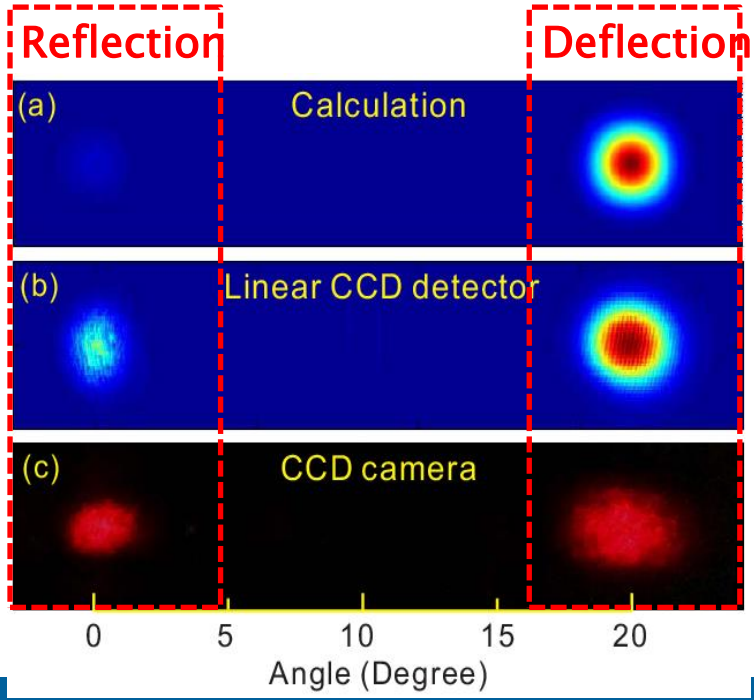




"Dielectric resonator nanoantennas at visible frequencies" Optics Express 21(1), 2013



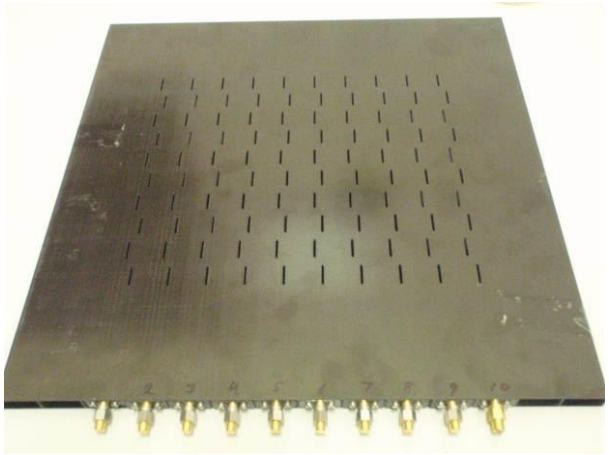
Scattered E field



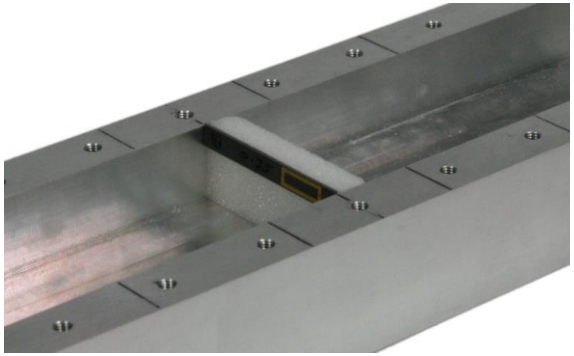
Antennas & Propagation Research at DSTO

Defence Science & Technology Organisation
Salisbury, S. Aust.
Editors: Prof. Bevan Bates & Dr Warren Marwood

Topics at DSTO



- Radar research at HF-VHF
  - modelling both antennas & propagation
  - applications of MIMO concepts at HF
  - terrain effects on forward-scatter ground reflection
- Antenna research at VHF-SHF
  - Antenna arrays that use beam-forming techniques for signal AOA determination
  - PCB broadband LPDA antennas
  - Slot arrays
- RF Propagation Research at VHF-EHF
  - development and validation of propagation models
  - the measurement and modelling of refractive index.
- Research at EHF (millimetric wave) and THz
  - integrated antennas
  - spatial processing for smart antennas
  - arrays
  - materials for antenna applications

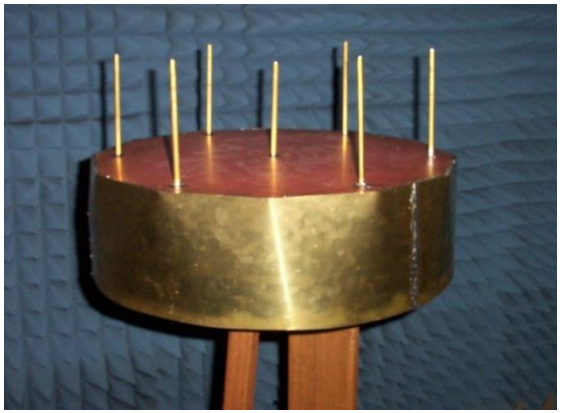


Electromagnetics Research at Griffith University

Griffith School of Engineering
Griffith University, Nathan Qld.
Leader: Prof David Thiel

Topics at Griffith U

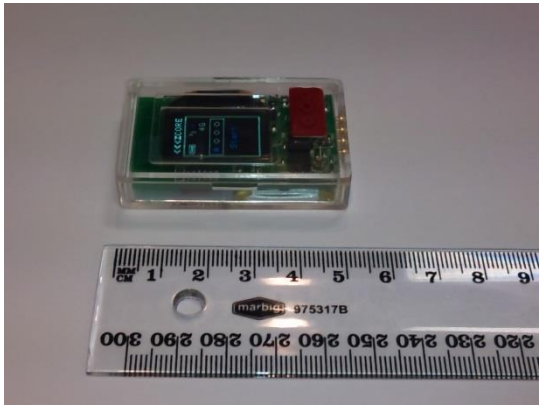
- Small antennas in difficult environments
- Small optimised antennas
- Sustainable ('green") electronics
  - Eg. Tapered meander-line for reduced metallisation
- Controlled beam antennas
  - Switched parasitic antennas (360° direction finding)
- ELF-VLF Geophysics probes



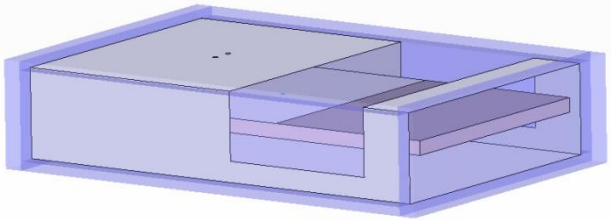
Seven element switched parasitic monopole antenna

Small antennas in difficult environments

- Reducing the effect of adjacent materials (eg wood, glass, human body, water etc)
- Modelling approaches to planar antennas and frequency selective surfaces on materials



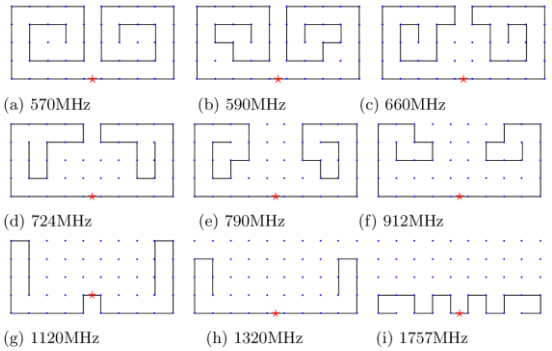
Sports sensor – 2.4 GHz



Slot antenna on a water-proof sensor

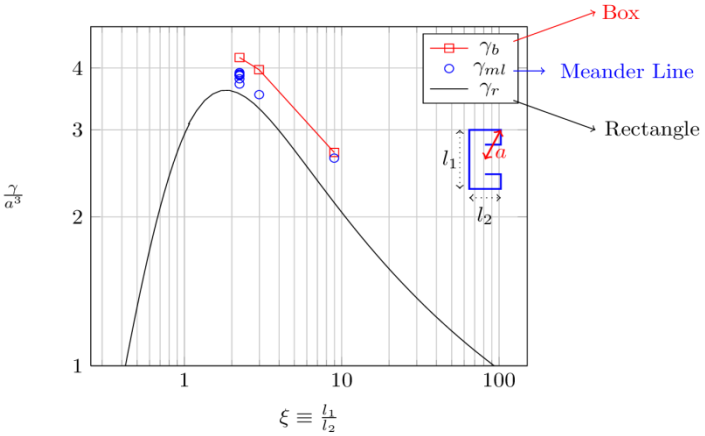
Small optimised antennas

- Meander line dipoles – optimization
- Fundamental limits research (Q, ka, bandwidth, polarizability approach)



Meander line dipoles – optimized for low f_0 and high efficiency

3D optimized antenna



Polarizability versus *l/w* ratio of optimised meander-line antenna compared to theoretical limits

Antennas & Propagation Research at La Trobe University

Department of Electronic Engineering
La Trobe University, Melbourne Vic
Leader: Prof. John Devlin

Topics at La Trobe U.

- Radar: Australian participant in SuperDARN
  - Involves engineering design and construction as well as research
  - Development of concepts for TIGER-3, a new generation digital radar system, intended to be located on Bruny Island, Tasmania, and Unwin, New Zealand

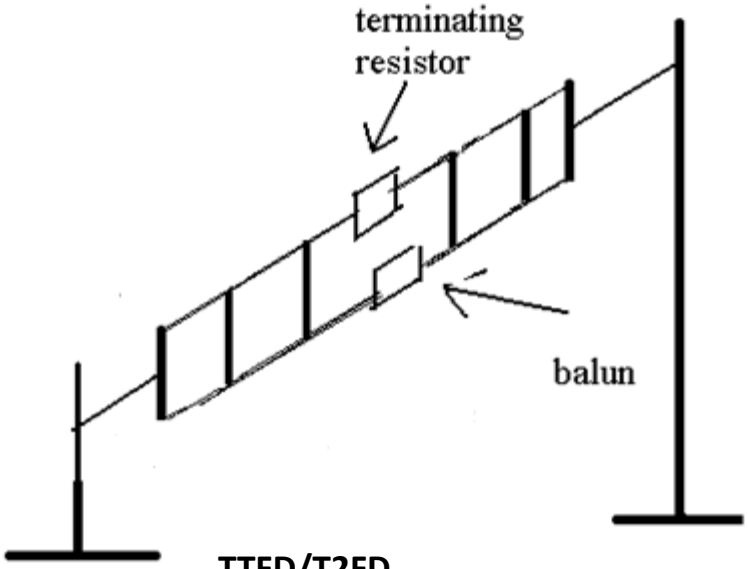
SuperDARN

- SuperDARN (Super **D**ual **A**uroral **R**adar **N**etwork) - Network of HF radars developed to study the motion of plasma in the Earth's high-latitude ionosphere.
- SuperDARN Radars are pulsed & operate in pairs as fixed frequency sounders, 8-20 MHz, 600W per transmitter
- Data aquired : Range, echo power, doppler shift and spectral width (velocity)
- Currently more than 25+ radars are operational globally, more under development
- TIGER (Tasman International Geospace Environment Radar) is the Australian consortium within the SuperDARN, operates 2 radars from La Trobe University
- La Trobe University Engineering is developing third TIGER radar (T3), deployment is underway

All hardware & software is designed by engineers at LTU

Alternative HF antenna

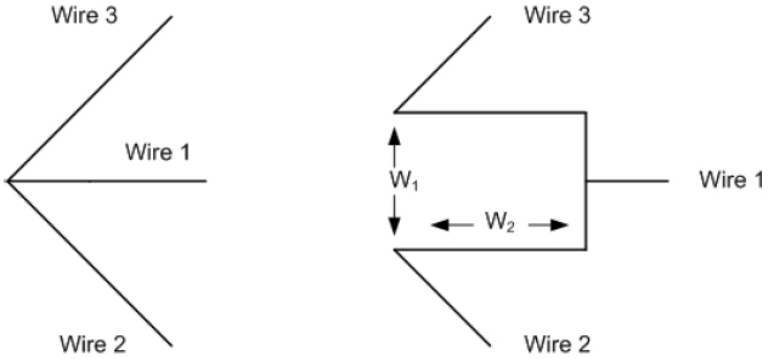
- Needed to reduce overall development and maintenance cost, allow easy construction
- Match or improve on LPDA gain, VSWR, azimuth beam width, take off angle and f/b ratio
- TTFD or T2FD (Tilted/Twisted Terminated Folded Dipole) has many names



TTFD/T2FD

- Used by amateur radio operators
- Easy construction, good SWR across HF band
- Lacks high gain, directivity and take of angle

Splice Model – 3 wire node & butt splice

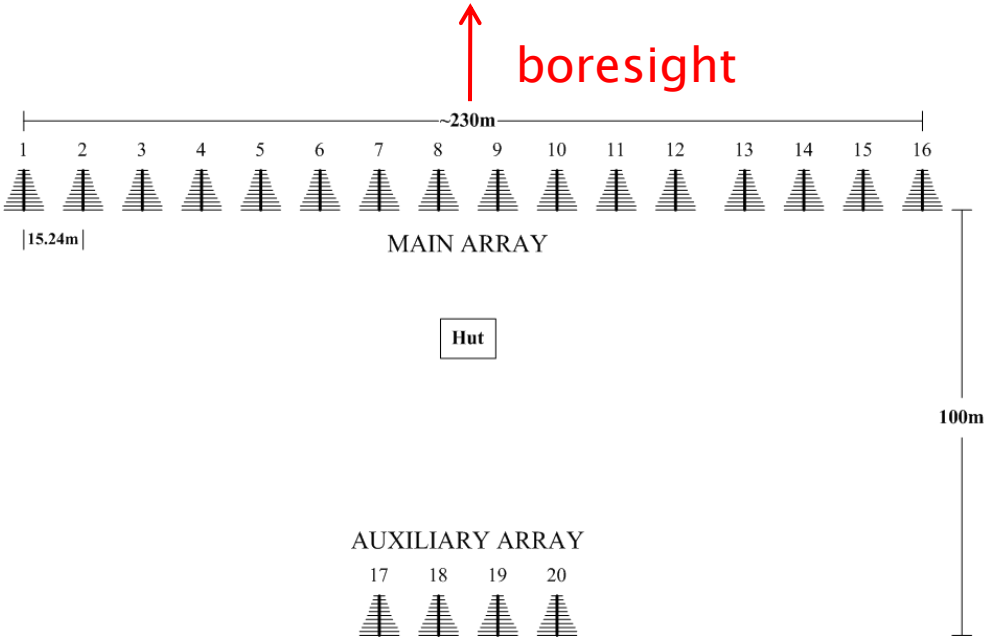


Modelled with butt splice currently used within the TTFD design with inner dimensions of W1 and W2 respectively.

Bruny & Unwin – Basic Specifications

Bruny Island, Tasmania TIGER Radar

- Each radar consists of 20 horizontally polarized Log Periodic (LPDA) antennas.
- The 16 antenna main array is used for both transmit and receive.
- A second four antenna (interferometer) receive only array is used to estimate angle of arrival (elevation).



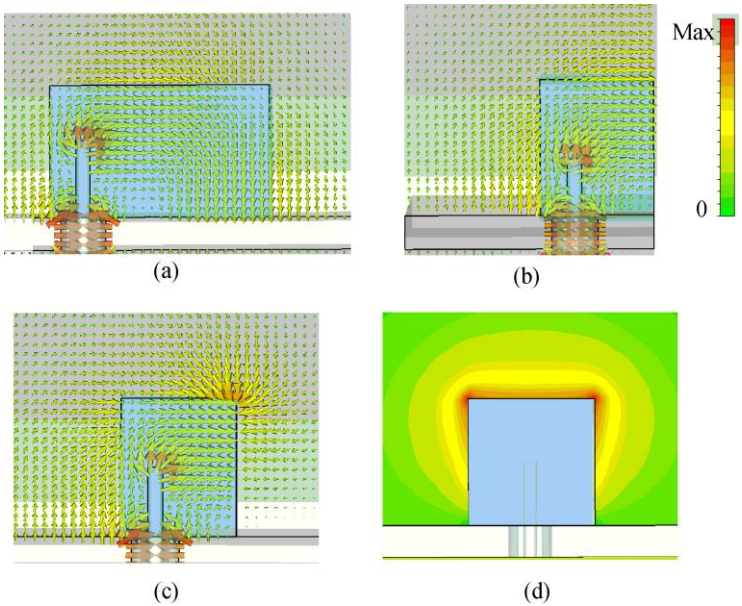
Centre for Electromagnetic & Antenna Engineering at Macquarie University

Department of Engineering
Macquarie University, Sydney NSW
Leader: Prof Karu Esselle

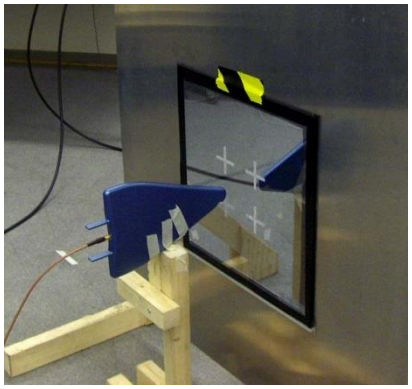
Topics at Macquarie University

- Reconfigurable antennas
- Fabry-Perot resonator antennas
  - development of new surfaces to increase bandwidth
- Dielectric resonator antennas
  - Imbedded cavities
  - Increase bandwidth
- Electromagnetic models
- FSS for energy-saving glass

Sample projects – CELANE

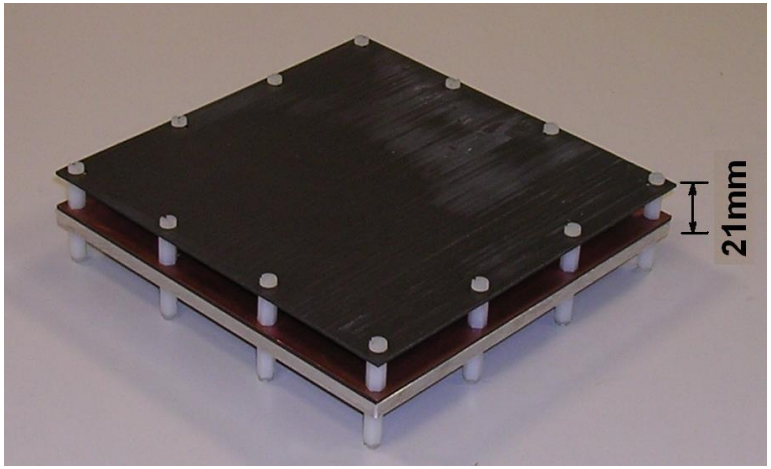


Compact DRA with 60%–110% BW



FSS for energy-saving glass panels

Super wide-band antennas (1:25)



Low-Profile Wideband EBG-based Fabry-Perot resonator antenna

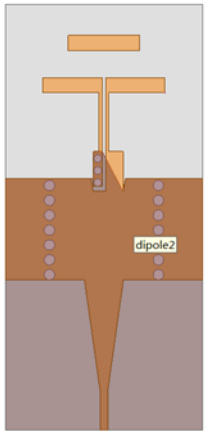
Antenna Research at University of New South Wales

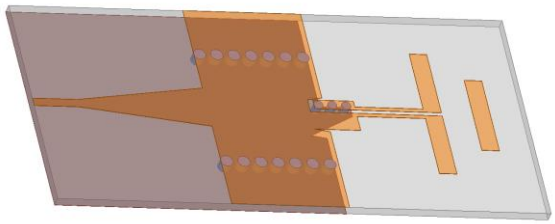
School of Electrical Engineering and Telecommunications
University of NSW, Sydney NSW
Leader: Prof. Rodica Ramer

Topics at University of NSW

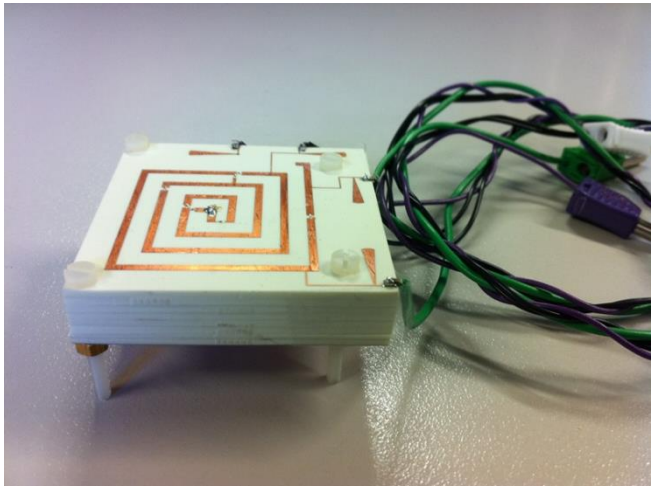
- Wideband microwave structures through reconfigurability
- MEMs enabled antennas

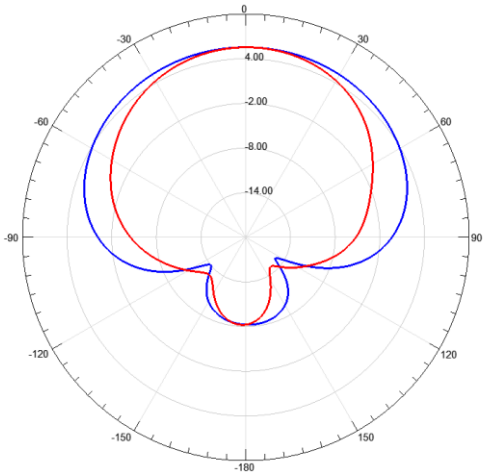
Sample Projects – UNSW

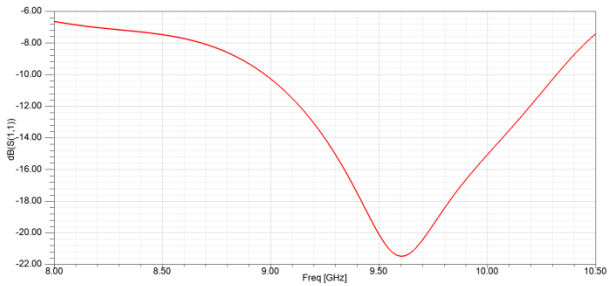




Yagi with MEMs







Spiral antennas with PIN and MEMs

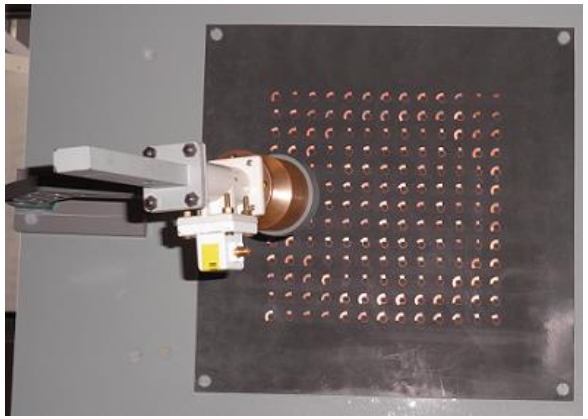
Antenna Research at University of Queensland

Electrical Engineering
University of Queensland, Brisbane Qld
Leader: Dr Amin Abbosh

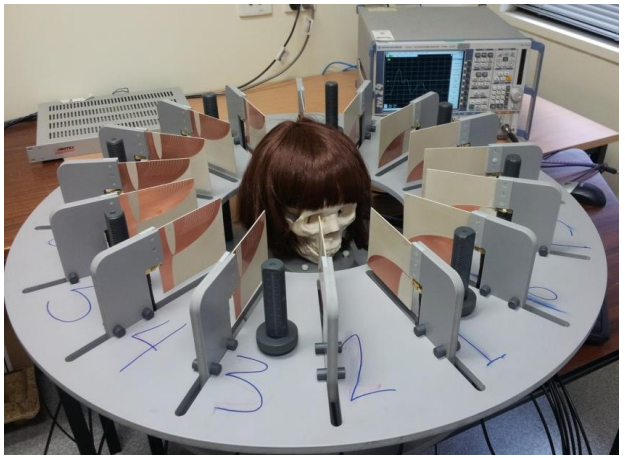
Topics at University of Queensland

- UWB antennas for imaging systems
- Three-dimensional antennas
- Reflectarrays
- Band-notched antennas
- Multi-band antennas

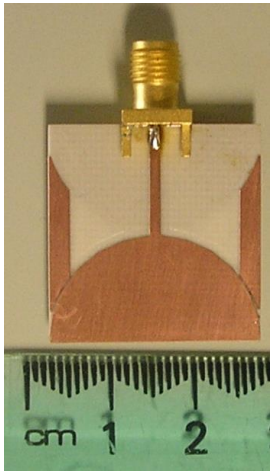
Sample Projects – UQ

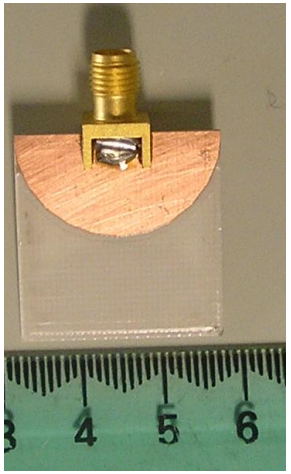


Reflectarrays

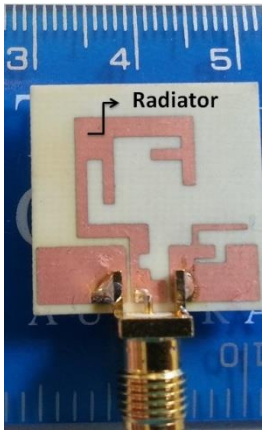


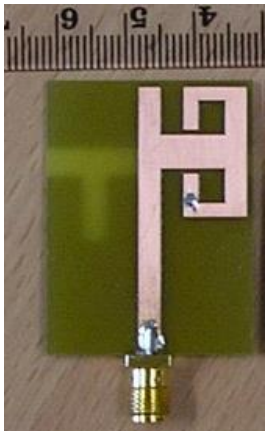
UWB antenna array for head imaging





Band-Notched Antennas





Multiband Antennas

Antenna Research at RMIT University

Electrical Engineering
RMIT University, Melbourne Vic.
Leader: Dr Kamran Ghorbani

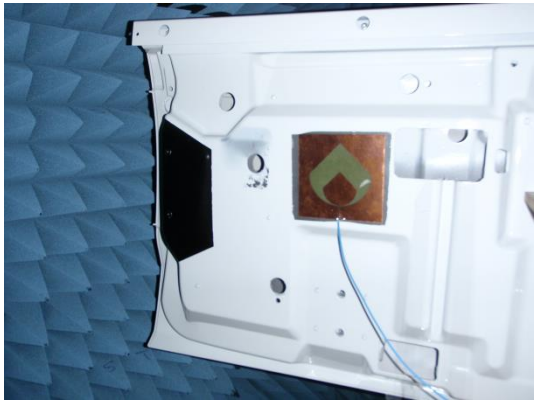
Topics at RMIT University

- Wideband Multi-service vehicular antenna
- Slotted waveguide antennas
  - stiffened structures
  - split-ring resonator loading
- Reconfigurable FSS
  - using a spring resonator element
- Detecting bushfires
  - using radar
  - dynamic measurement of the attenuation of fire ash particles in eucalypt forests

Sample Projects – RMIT

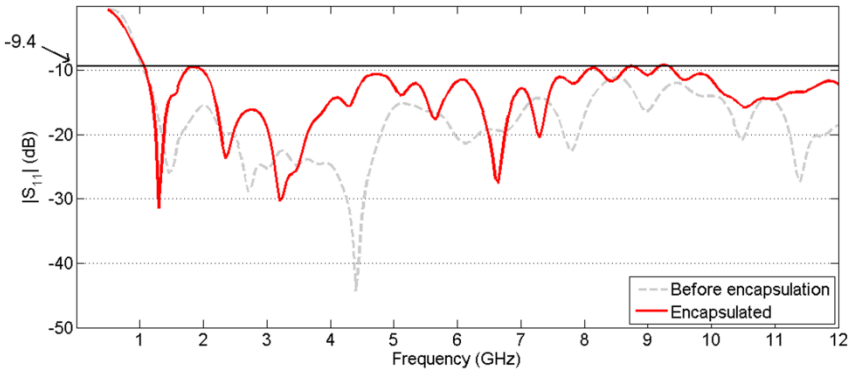
Wideband Multi-Service Vehicular Antenna

HSV Maloo tailgate assembly with embedded antenna in the anechoic chamber



Tailgate with antenna embedded and connected to coaxial cable.

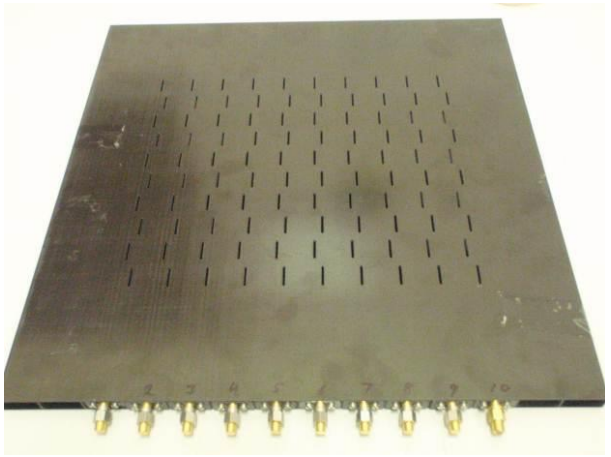
Ref: Pell et al.: "Experimental study of the effect of modern automotive paints on vehicular antennas" IEEE TAP, 59, pp. 434 – 442, 2011



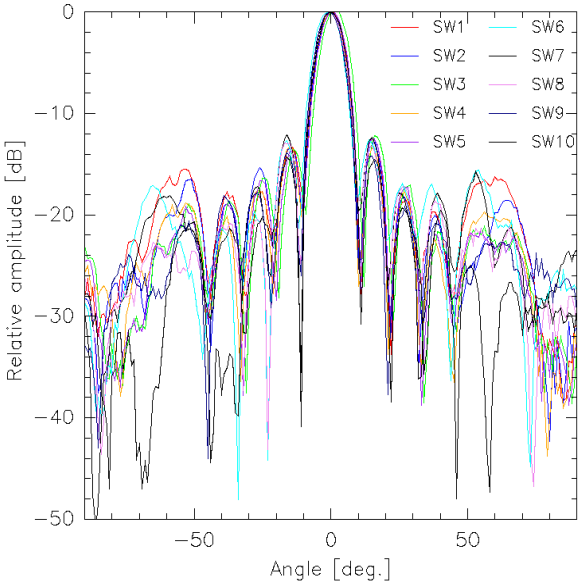
Measured reflection coefficient for the antenna when encapsulated in the ute (HSV Maloo) tailgate.

Slotted Waveguide Antenna Stiffened Structure (SWASS)

A slot in the first 1 x 10 array being cut in the CNC router.



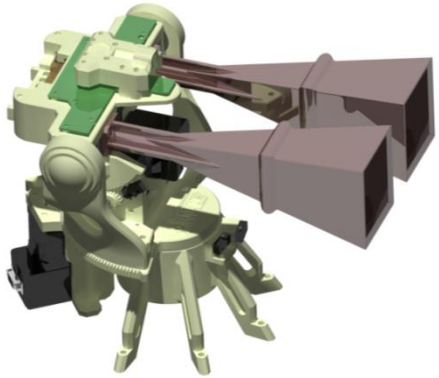
A completed SWASS panel containing a 10 x 10 slot antenna array, RF feeds and CFRP end-

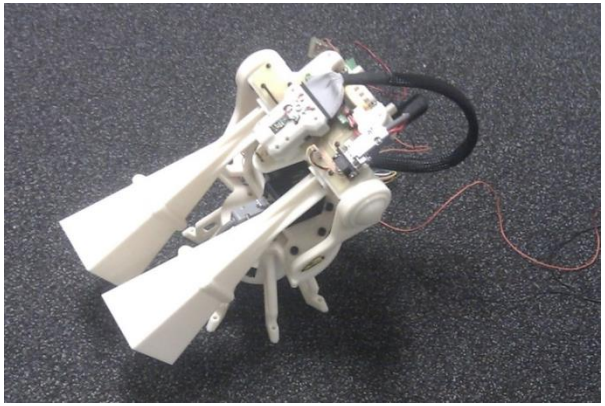


Measure radiation pattern at 10 GHz of each of 1 x 10 uniform array elements of the 10 x 10 planar antenna arrays.

Ref: Gray et al.: "Carbon fibre reinforce plastic slotted waveguide antenna", APMC 2010, pp. 307-311.

Dynamic Measurement of the Attenuation of Eucalypt-based Forest Fire Ash Particles





38 GHz Radar fabricated at RMIT, printed and plated horns in copper then gold

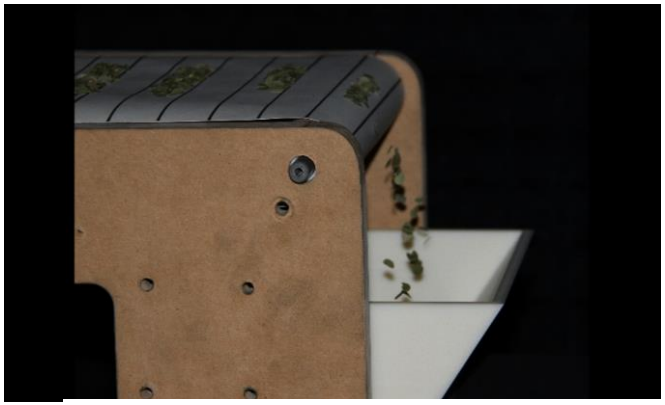
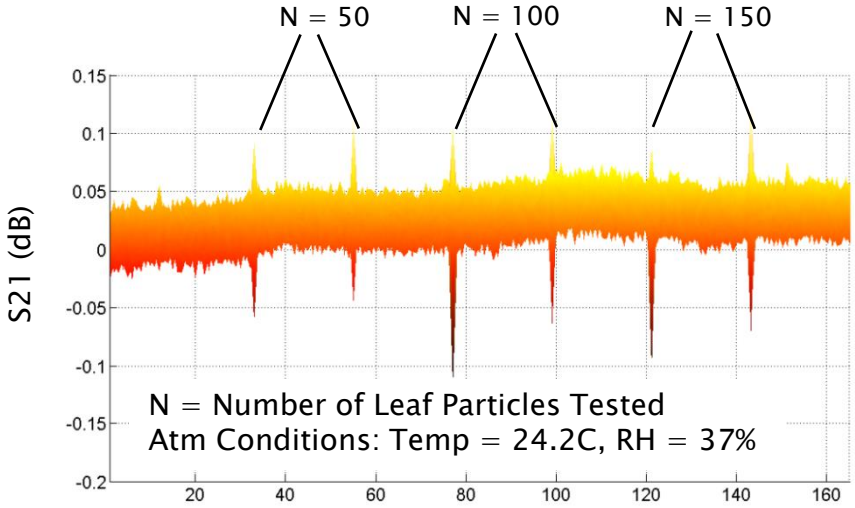


Illustration of the dynamic behavior of the particles as they fall through attenuation measurement setup.



Measured attenuation for a specific number of controlled particles based on complex permittivity, permeability and geometry at 38GHz.

Electromagnetics & Antenna Research at CSIRO

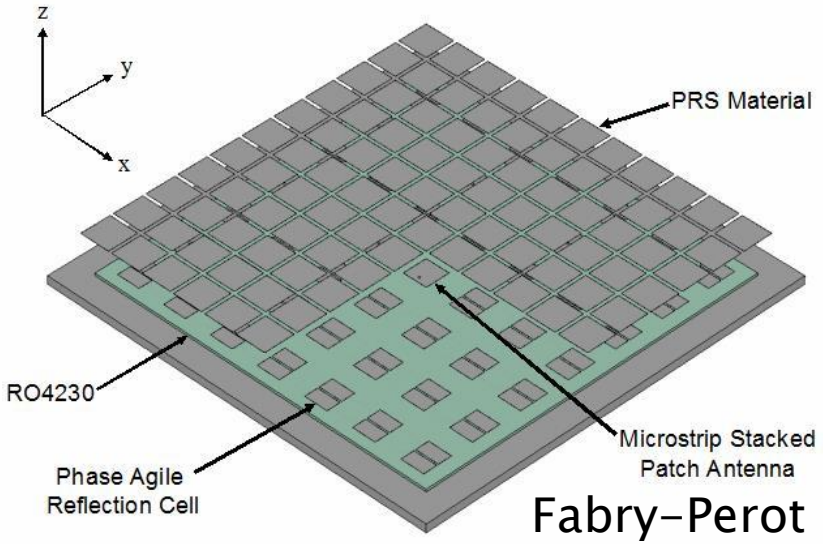
Computational Informatics
Marsfield, Sydney NSW
Leader: Dr Stuart Hay

Topics at CSIRO

- Reconfigurable antennas
- Design through optimization of geometry
- Millimetre-wave and THz Antennas and systems
- Reflectors, lenses and feeds
- Wideband phased arrays
  - SKA focal plane array feeds
  - general arrays

Reconfigurable Antennas

- Reconfigurable in:
  - Geometry
  - Polarization
  - Frequency

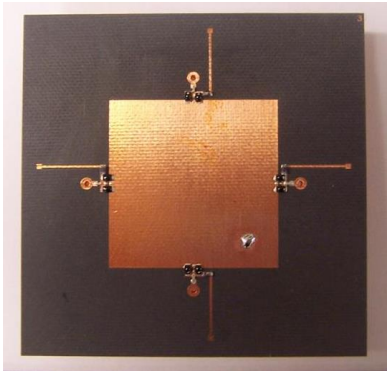


Fabry-Perot

Ref: Weily, et al., IEEE TAP 56, 11, 2008

Yagi

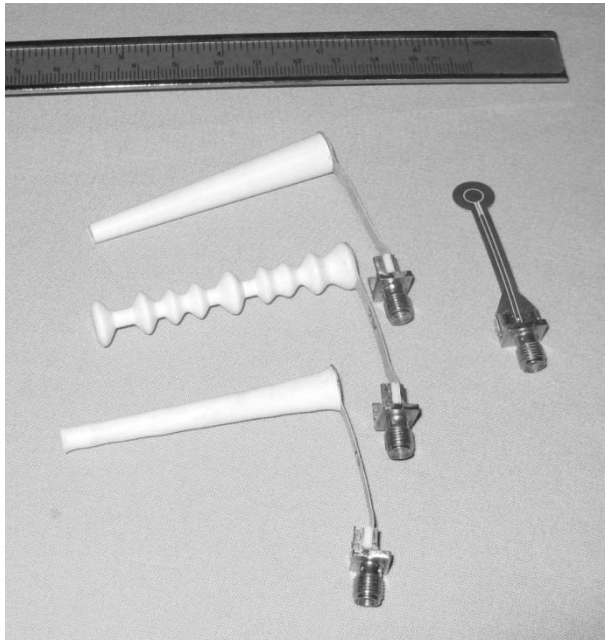
Refs: Qin, et al. IEEE TAP, 58, 8, 2010
& IEEE TAP, 58,10, 2010.

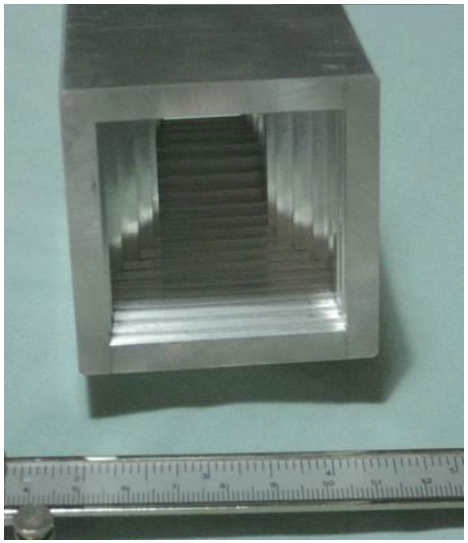


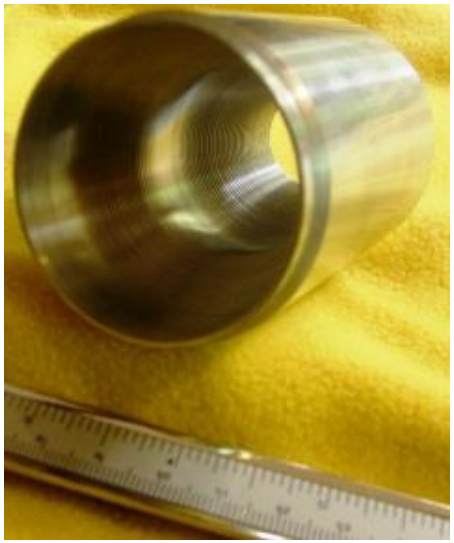
Microstrip

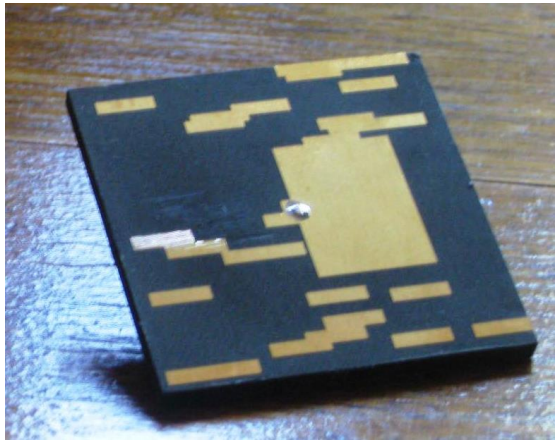
Antenna Design Through Optimization of Geometry

- Profiled horns
- Profiled dielectric rods
- Swarm antennas – parasitic patches



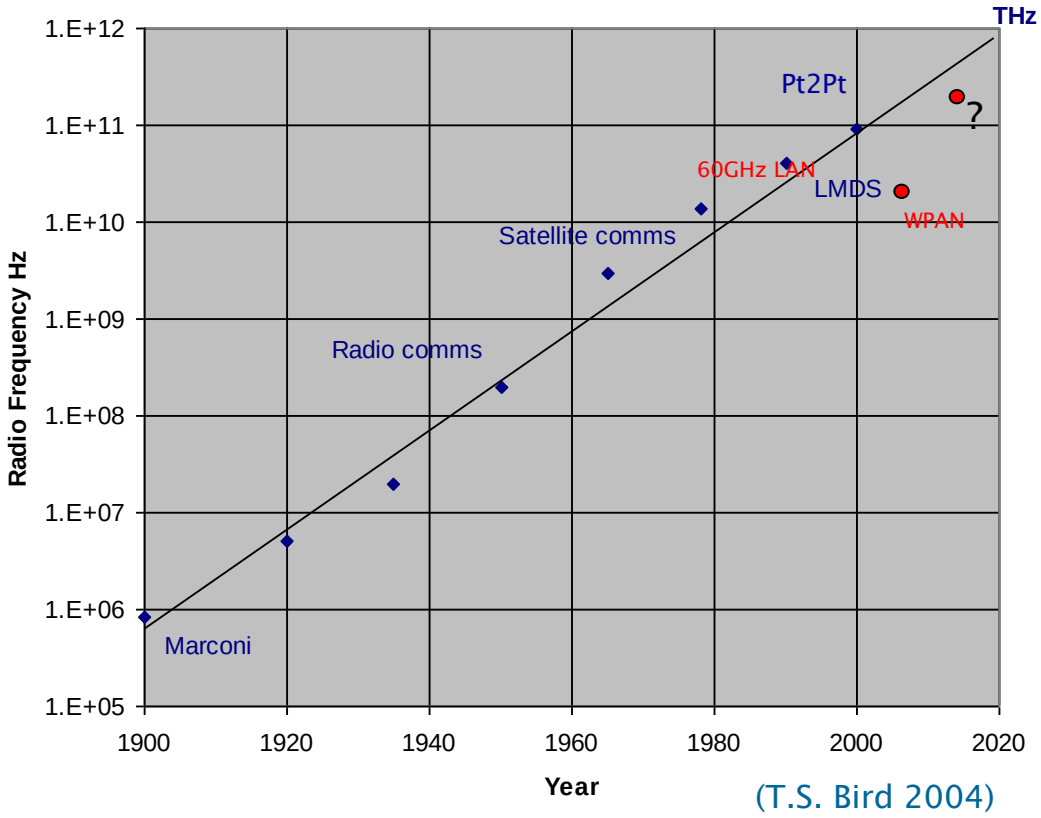






Looking Ahead – Towards Terahertz

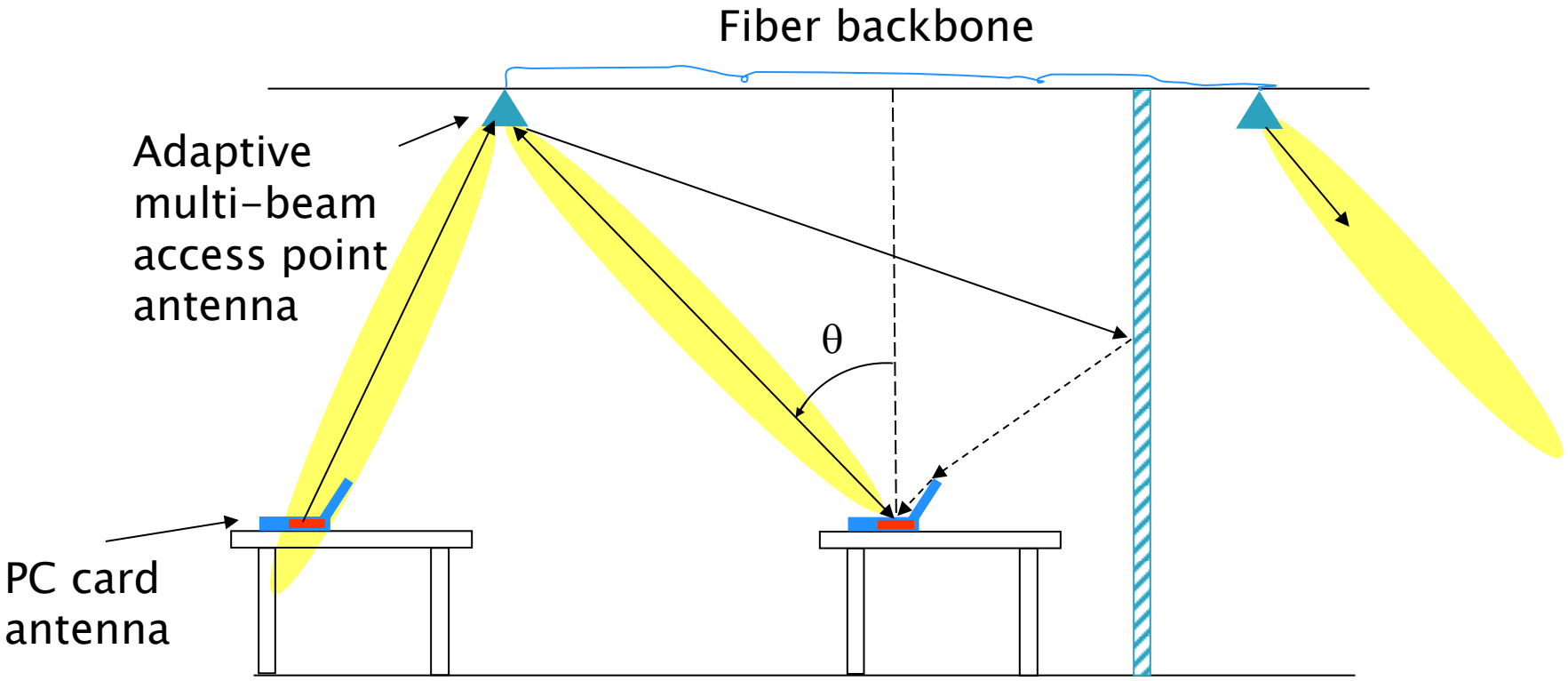
- Use of the radio spectrum has seen the upper frequency for communications increasing 10 times every 20 years
- At this rate, by 2020, 0.5 to 1 THz will be used for wireless communication



(T.S. Bird 2004)

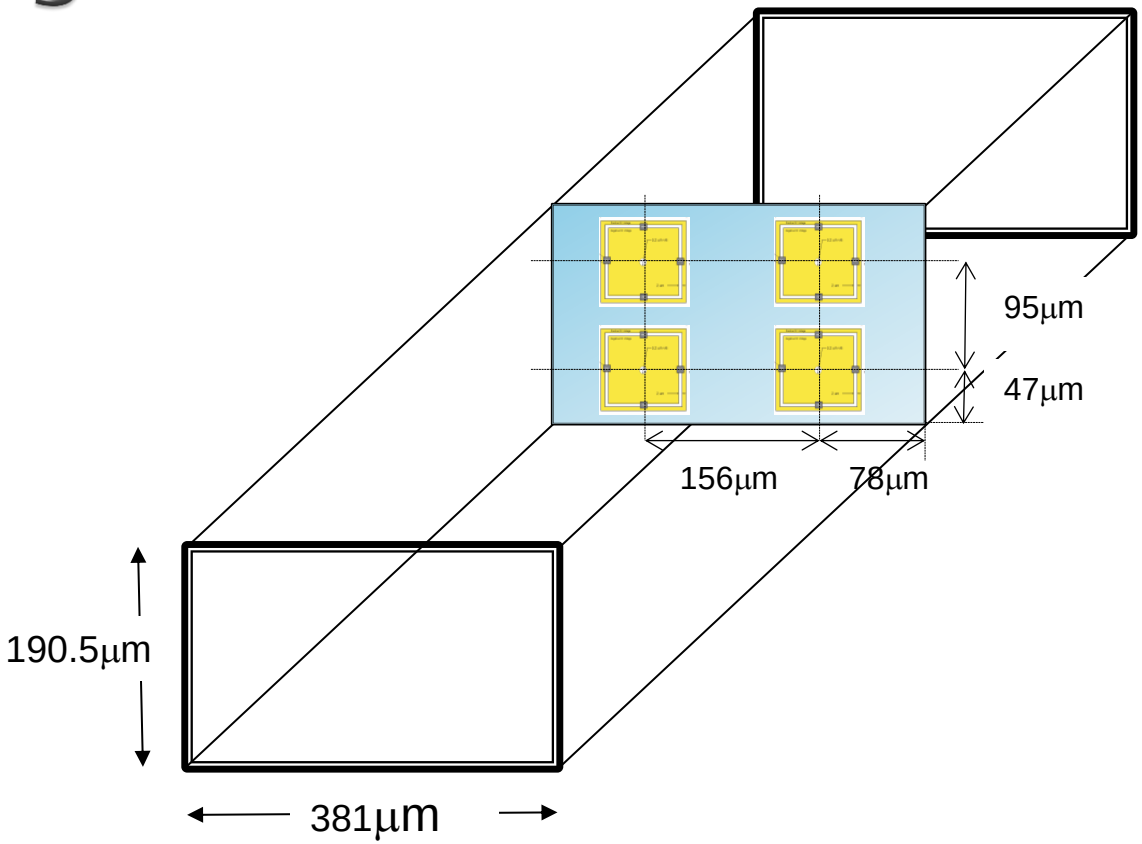
Ref.: T.S. Bird et al., "Terahertz imaging from an RF engineering perspective", DSTO Workshop on TeraHertz for Defence and Security, Dec. 16-17, 2004, Adelaide, Australia

Proposed THz Wireless LAN



Ref.: T.S. Bird et al.: "Antennas for future very-high throughput wireless LANs", IEEE APS Symposium, 2008

THz Modulation with 4x4 FSS Waveguide



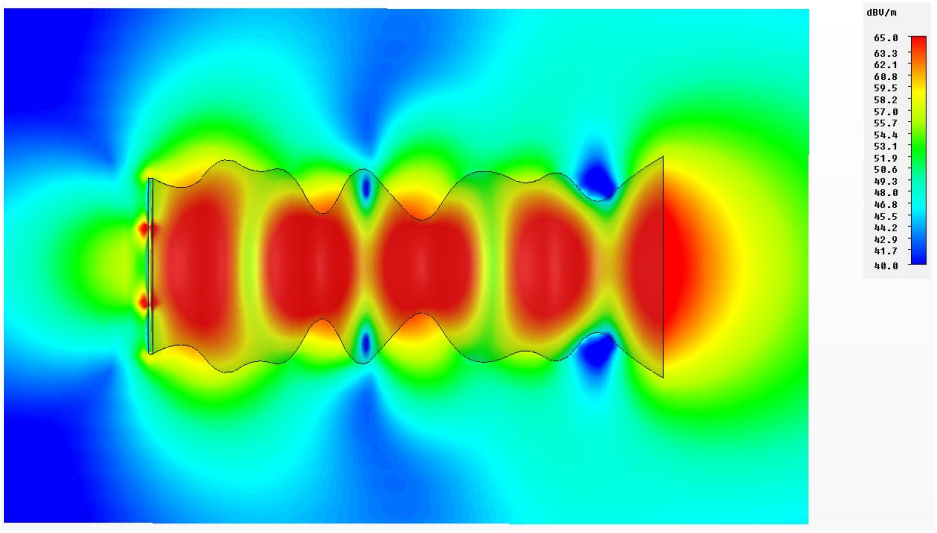
Waveguide: WR-1.5 Frequency range: 500 to 750 GHz size: 0.0150'' x 0.0075''

Ref. Kiani & Bird, Radio Science, Vol. 46, 2011.

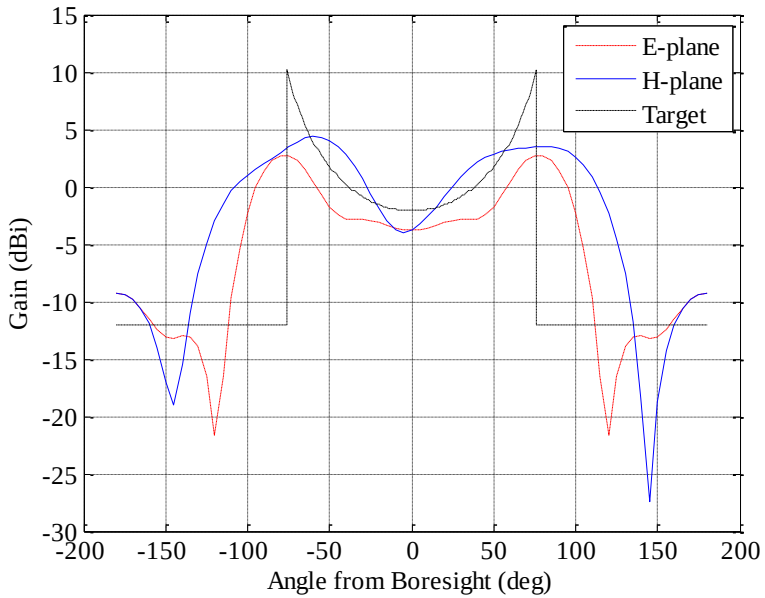
THz Dielectric Rod Antennas

- 600GHz dielectric rod antenna with high efficiency ring-slot feed

Shaped Beam for WLAN – Profiled Dielectric Rod



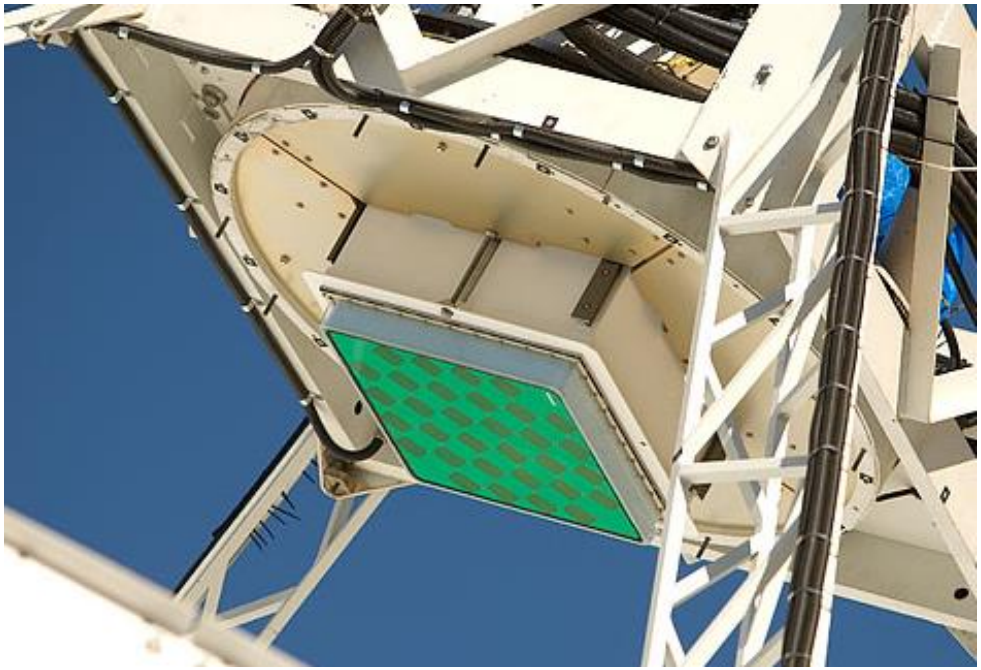
Amplitude of the radiating electric field



Simulated & measured radiation patterns with mask

Ref: Hanham et al.: "Evolved-profile dielectric rod antennas", IEEE TAP, 59, No. 4, 2011, pp. 1113-1122.

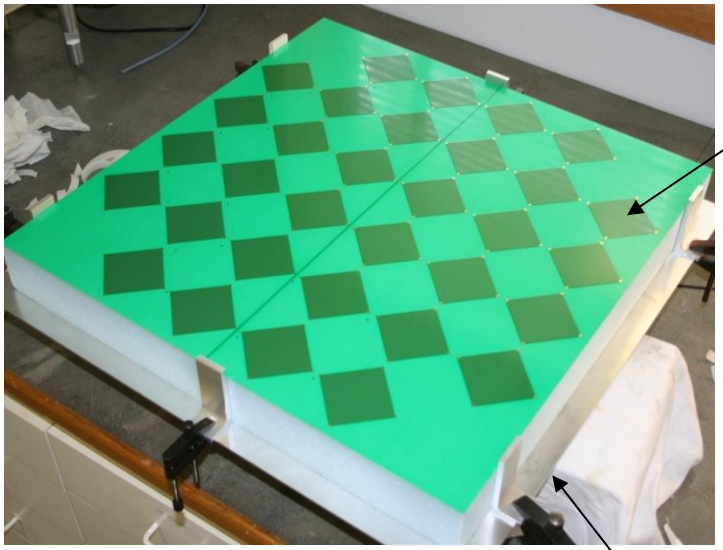
Wideband Phased Array Feeds

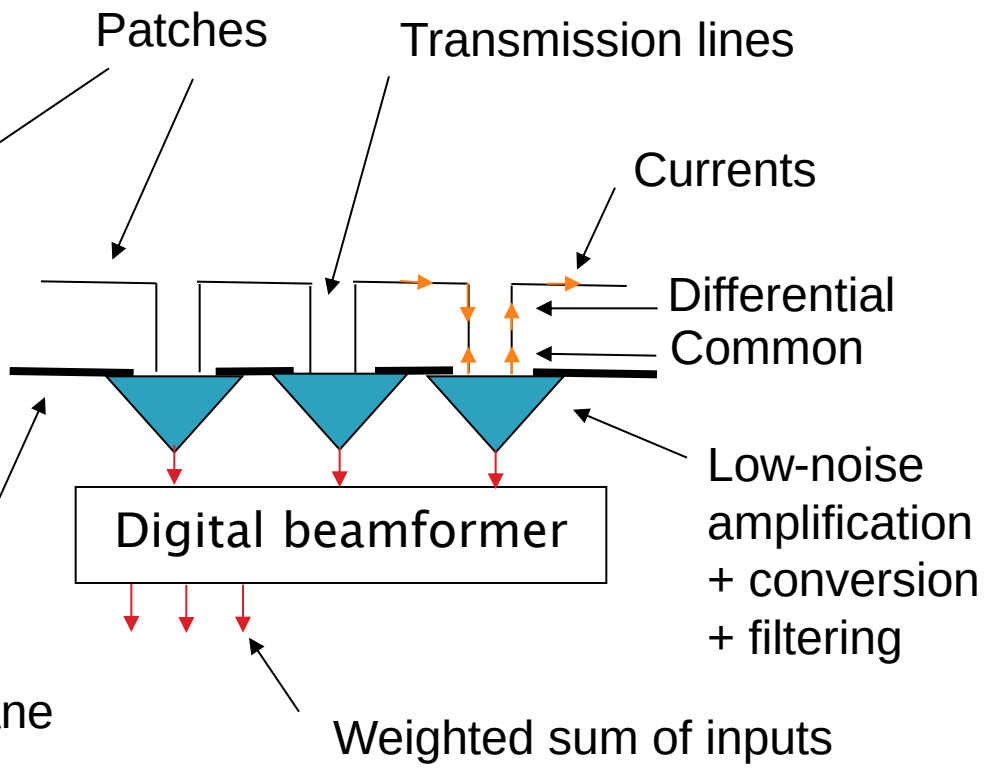


- Next-generation ‘radio camera’ feeds for radio telescopes

Ref: Hay and O’Sullivan, Radio Science, 43, RS4S06, Dec 2008.

Connected-array Phased Array Feed

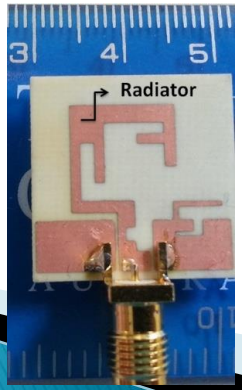


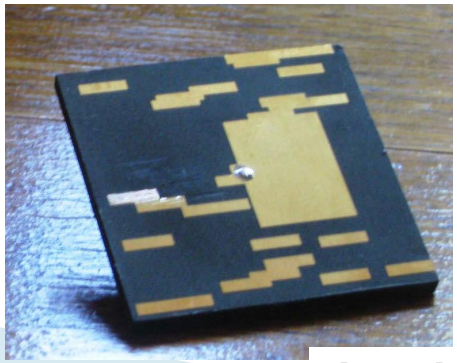


- Dual polarized connected planar array
- Array and low-noise amplifier matching (300ohm)
- Wideband (>2.5:1)
- Advantages in integration

Conclusion

- Australian antenna research is providing solutions to global wireless problems
  - Data rate, speed, bandwidth, size
  - Avoiding the temptation to develop gadgets for the wireless revolution
- Have a tradition of employing challenging applications to lead new developments
- Only a few topics of specific application to Australia. Those are:
  - Bushfire detection/monitoring, radio astronomy, ionosphere monitoring
- More research needed in materials including metamaterials applicable to millimetre-wave & THz frequencies.

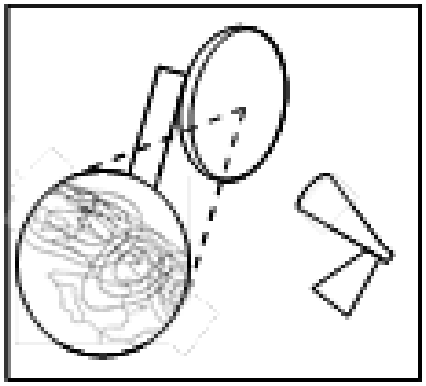




Thank You

- Further Contact:

Dr Trevor S. Bird
Principal, Antengenuity & CSIRO Fellow
PO Box 306
Eastwood, NSW 2122
Australia
Email: ts.bird@ieee.org



CSIRO

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